15 DESIGN AND CONSTRUCTION OF MULTIFAMILY DWELLINGS

As the growing population is extruded into urbanized areas, multifamily dwellings must be constructed to accommodate the higher densities. Pressures of population and cost force people together, and noise and noise transmission between occupied spaces become significant concerns. People want their homes to be quiet and free from intrusions, like a single-family residence. The most common complaints are about noise transmission through floor-ceilings, footfall noise, and noise due to the movement of people on floors and stairways. The next most common problem is audibility of plumbing and piping. Airborne noise transmission can also be problematic, but is encountered less frequently.

The design and construction of multifamily dwellings must include consideration of privacy, which in many cases is legally mandated; even if it is not controlled by a building code or property line ordinance, it nevertheless forms part of the basis of the home buyer's or occupant's reasonable expectation of quality. If the dwelling, by dint of its construction, does not meet this expectation there may be sufficient cause for the finding of a construction defect in the building for which the developer and his design team may be held liable. As the perceived quality of a residence increases, so too do the expectations for a quiet environment. This perception of quality may be based on cost, location, sales information provided to the buyer, or due to the fact that a person is purchasing a permanent home rather than renting an apartment.

Since buildings increasingly are constructed from lightweight materials, the sound transmission between spaces increases. In the older masonry and concrete structures, the mass law insured that isolation would be quite high. The exigencies of cost and time have pushed building construction toward lighter and lighter materials, and hence to greater sound transmission. Given these very real constraints it is incumbent upon architects and engineers to find ways of providing adequate sound isolation in residential structures using the commonly available materials. Where dwelling units are separated by design, good results can be achieved without heroic measures. For example, in multifamily dwellings a townhouse plan is preferred over stacked units to avoid common floor-ceilings. When multistory units are necessary, a plan that stacks similar rooms, one above another, avoids incompatible uses such as a bathroom located above a bedroom. Closets and other nonsensitive spaces can be located on party walls to provide additional shielding.

15.1 CODES AND STANDARDS

Sound Transmission Class—STC

In Chapt. 9 we discussed the formal procedures for the measurement of the airborne sound transmission loss and the determination of the sound transmission class (STC) of a partition. The STC is a weighted average of the transmission loss values at 16 third-octave band frequencies, which is normalized using the area of the common partition and the absorption in the receiving room. Many cities and states have adopted minimum code standards for the STC ratings in multifamily dwellings and these can be used to develop prudent design objectives for various levels of construction quality.

The legally mandated minimum STC ratings are usually set to 50 (State of California, 1974; the Uniform Building Code or UBC, Appendix Chapter 35, 1982); however, in some cases stricter standards have been adopted. For example, the City of Redondo Beach, CA requires a minimum STC of 55 in condominium homes. Under field conditions the measured FSTC rating is about five points lower than the laboratory rating, and this difference is acknowledged in the building code. Thus if a field test is performed to check the rating of a separation after the building has been completed, an FSTC 45 is the minimum allowed under UBC requirements.

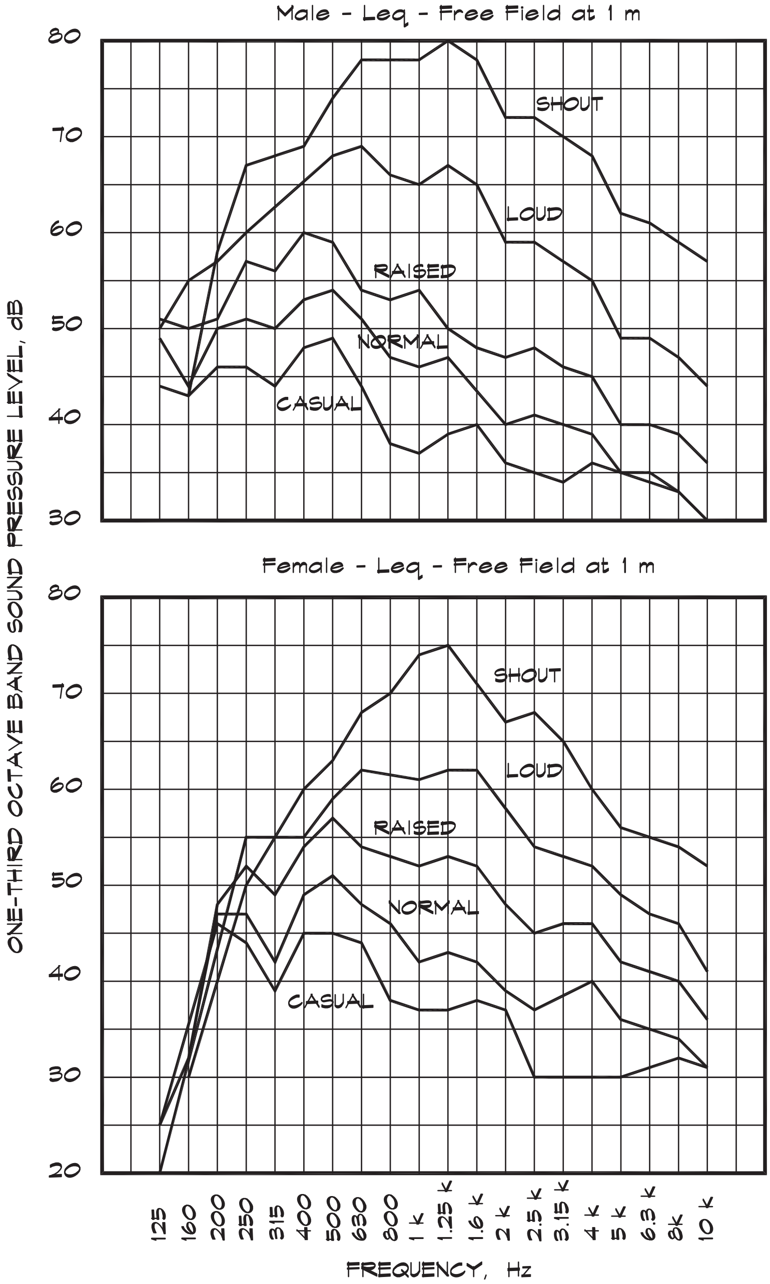
In California (Title 24 CAC, 1990), the NIC, which is an FSTC measurement based on the noise reduction without normalization, is allowed to be measured in lieu of the FSTC. The NIC, defined in Chapt. 9, is generally three to five points higher than the FSTC, and varies from room to room depending on the absorption in the receiving space. Thus this provision not only introduces a substantial weakening of the FSTC 45 minimum code standard, but also presents a standard, which may not be representative of the type of partition being tested.

An STC 50 may be the lowest allowable laboratory rating for a given partition. This does not necessarily represent a level of quality that guarantees owner satisfaction with the dwelling or acoustical privacy between units. Rather, it is the minimum level of quality legally acceptable; it is illegal to build a building any worse. The degree of isolation for airborne noise transmission depends not only on the building construction but also on the type of source, the level of the noise, and on the background noise in the receiving space. Table 15.1 and Fig. 15.1 give the assumptions used in a hypothetical sound transmission calculation. The music spectrum is taken to be flat between 125 Hz and 1000 Hz and rolls off 3 dB per octave above and below these limits. Calculations lead us to the levels shown in Table 15.2. The background level is typical of that found in a quiet bedroom at night.

TABLE 15.1 Source and Background Level Assumptions

Source Level	Receiver Level
Normal Voice = 58 dBA at 3’	Understandable => 30 dBA
Raised Voice = 65 dBA at 3’	Plainly Audible => 25 dBA
Loud Voice = 75 dBA at 3’	Background = 25 dBA
Shouting Voice = 88 dBA at 3’	Audible => 20 dBA
Loud Stereo = 95 dBA at 3’	Not Audible < 20 dBA

FIGURE 15.1 Male and Female Speech Spectra (Pearsons et al., 1977)



The calculations in Tables 15.1 and 15.2 are meant to be illustrative rather than being a result that holds for all sources and wall types. They give a portrait of the transmission of various source levels between spaces and demonstrate that not all sources, even if they are voice, generate the same level, and that minimum code compliance is not necessarily sufficient for adequate acoustical isolation. At the upper end of the level range the numbers show the problems encountered in the design of recording studios where high acoustic levels occur near very quiet recording spaces.

TABLE 15.2 Sound Transmission Class vs Expected Field Result

STC	FSTC	Expected Field Result
80	75	Very loud music audible
75	70	Very loud music plainly audible
70	65	Very loud music understandable
		No unamplified voice audible
65	60	Shouting audible
		Loud voice not audible
60	55	Shouting plainly audible
		Loud voice audible
55	50	Shouting voice understandable
		Loud voice plainly audible
50	45	Loud voice understandable
		Raised voice not audible
45	40	Raised voice plainly audible
		Normal voice not audible

Reasonable Expectation of the Buyer

In selecting the appropriate design criterion for a given level of quality the designer should consider the type of building and the reasonable expectation of quality of the buyer. Unfortunately, too often builders put money into the appearance of a residential building but little into noise isolation. The words *luxury* or *high quality* or *soundproof* are sometimes used to describe projects that barely meet minimum code requirements. If a builder or sales broker is going to characterize the product in this manner, he is well advised to provide a level of noise control commensurate with the description.

Multifamily dwellings can be grouped into three quality categories as shown in Table 15.3. Table 15.4 shows general guidelines according to the level of quality, which assumes a minimum code standard of STC 50.

TABLE 15.3 Level of Quality vs Type of Use

Classification	Residential Use
Minimum Quality	Normal Apartments
	Hotels and Motels
	Nursing Homes
	Hospitals
Medium Quality	Good Apartments
	Normal Condominiums
High Quality	High Quality Condominiums

TABLE 15.4 Sound Transmission Class vs Level of Quality for Party Wall and Floor-Ceiling Construction

Classification	STC	FSTC
Minimum Code	50	45
Minimum Quality	55	50
Medium Quality	60	55
High Quality	65	60

To achieve a minimum code standard of STC 50, one should design to the code plus a reasonable safety factor. Generally low-cost rental property, subsistence housing, and temporary housing such as hotels and motels would be designed to the minimum-quality level. Note that the minimum-quality design level is not the same as minimum-code level, since there must be a certain safety factor included to assure code compliance. If one were to design exactly to the code minimum it would mean that the selected construction would have a 50% probability of passing a field test. This is not considered good design practice, and a 3–5 dB minimum margin of safety is recommended. In practice, published test results for a given wall or floor will vary by a few points. It is prudent to examine the range of test results for a given configuration and to expect the lowest values in the test range rather than the highest.

The medium-quality level is appropriate for use for high-quality apartments and normal condominiums. In general, any condominium should be designed to at least the medium quality standard. If noise problems arise, the owner of a condominium does not have the freedom of movement of an apartment dweller. Under California law the seller must reveal any known defects to a potential buyer, including any problems associated with noise transmission. A first-time condominium purchaser may be moving from a single family home and have an expectation of quality based on his previous housing experience.

Into the high-quality category fall those condominiums where there is a level of isolation similar to that found in a single family home. In these cases owners may complain if they can hear any activities in adjacent dwelling units. They are particularly sensitive to footfall and plumbing noise since these may occur relatively frequently. Even for this type of structure the ratings given in Table 15.4 will not guarantee isolation of every noise, as illustrated in Table 15.2.

Impact Insulation Class—IIC

Minimum IIC ratings are set to 50 in the UBC with a minimum field tested FIIC of 45 allowed. At this rating, footfall noise is quite pronounced and very audible in the unit below. In response some cities and condominium associations have adopted more stringent laws. The City of Redondo Beach, for example, sets a minimum IIC rating of 65 in condominiums. Other cities such as Beverly Hills control noise through a property line ordinance as discussed next. The point at which footfall-generated impact noise becomes inaudible is closer to an IIC of 75, as shown in Fig. 12.23. The level of quality due a buyer in the control of impact-generated noise is numerically higher than that for airborne noise.

TABLE 15.5 Impact Insulation Class vs Level of Construction for Party Floor-Ceiling Construction

Classification	IIC	FIIC
Minimum Code	50	45
Minimum Quality	55	50
Medium Quality	65	60
High Quality	75	70

Property Line Ordinances

Cities and counties have ordinances restricting the levels of noise that are allowed within a real property boundary. These are known as property line ordinances and are tied to the zoning of the receiving property. Allowable levels are based on a measured or assumed ambient level within the receiving property, since a noise maker cannot be expected to be responsible for noise generated by other sources. A law usually establishes an absolute maximum at a level 5 dBA above the higher of the measured or assumed ambient. Normally the assumed ambient is reduced at night (before 7 AM and after 10 PM) by 10 dB to account for our increased sensitivity. Assumed ambient background levels provide the basis for the lowest level to which a standard may fall. For example in the City of Los Angeles, the nighttime assumed ambient is 40 dBA, so a noise maker would be allowed to create 45 dBA, even if the actual ambient background were below 40 dBA. This approach gives the noise maker a clear numeric design target even if the actual ambient falls below the assumed ambient.

The wording of these ordinances varies. Some are stated in terms of an absolute level such as the US EPA Model Noise Ordinance (1973), which reads:

> "No person shall operate or cause to be operated on private property any source of sound in such a manner as to create a sound level, which exceeds the limits set forth for the receiving land use category in Table __ when measured at or within the property boundary of the receiving land use."

In this case the ambient must still be taken into consideration since the ordinance applies only to the intrusive source.

The specific wording of an ordinance, particularly the definition section, is important. In many cases they set maximum limits on interior noise levels, which apply within the property boundaries of a dwelling unit. Thus if a person in one unit walks across a floor or turns on a tub faucet and the occupant of another unit is subjected to a noise in excess of the property line ordinance, there may be a cause of action against the builder who caused the condition to exist. It is not an action that is taken against the occupant unless the noise-making activity is unusual or excessive, such as playing a stereo too loudly, or unless the owner has changed the construction so as to worsen its sound reduction capability, for example by replacing a carpeted floor with a wood or tile floor. If an occupant runs the bath or shower, this would not be considered an unusual activity. If, however, he is doing midnight body slams, the resulting noise could not necessarily be blamed entirely on the developer.

TABLE 15.6 Recommended Maximum Interior Day Night Noise Levels from Exterior Sources

Classification	L_{dn} (dBA)
Minimum Code	45
Minimum Quality	40
Medium Quality	35
High Quality	30

Under California law developers are liable for the cost of testing and repair if party wall or floor-ceiling separations do not meet the minimum codes. Architects and engineers who design multifamily dwellings are well advised to consult local property line ordinances to make sure they are in compliance. The City of Beverly Hills, for example, limits interior noise levels to no more than 5 dB over the actual interior ambient. This is not an unusual provision; however, Beverly Hills defines the ambient as the quietest level present at any time of day at a given location with no minimum. An ordinance of this type can put a greater restriction on intrusive noise levels than a minimum STC or IIC rating does.

Exterior to Interior Noise Standards

The State of California (CAC Title 25, 1974) and other regulating bodies set maximum allowable interior levels generated by exterior noise sources such as street traffic. Housing and Urban Development (HUD) financed housing projects are subject to the same interior requirements (24 CFR 51B, 1979) as well as additional exterior requirements. Under both California law and the HUD regulations the limit is an interior L_{dn} of 45 dBA. In much the same way as the limits on STC and IIC were minimum code levels, so too are the allowable interior noise levels. Occupants are seldom happy with the minimum code noise level. Table 15.6 lists recommended interior levels for different types of construction quality. The interior standards assume that all windows and doors are closed so that adequate mechanical ventilation must be provided.

15.2 PARTY WALL CONSTRUCTION

General Principles

In actual building practice there are relatively few construction materials that are utilized, and a knowledge of transmission loss theory is most helpful in properly applying them. The most common materials are concrete, concrete masonry units (cmu), stucco, gypsum plaster, gypboard, and wood or metal sheets in various combinations. The structural supports are wood or metal studs for walls, and concrete, steel, or wood-joist systems for floors.

At low frequencies providing adequate stiffness and mass are the most important factors in achieving high transmission loss values. Stiffness can be increased by decreasing the support span and by increasing the bending stiffness. Short-span concrete slabs have both high mass and a large intrinsic stiffness and thus give excellent low-frequency transmission loss. Fully grouted cmu blocks or brick can provide nearly as much mass and stiffness; however, concrete blocks have significant porosity and must be sealed with an oil-based paint or plaster to realize the full effectiveness of their mass. Double concrete or cmu walls can be used, but the spacing between panels must be sufficiently large that the two are not coupled through the air gap. Usually at least 10 to 15 cm (4” – 6”) of spacing is required. Details of the STC ratings were discussed in Chapt. 10.

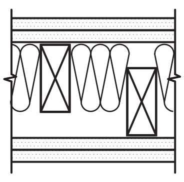
At higher frequencies, separately supported gypboard partitions, which have a high critical frequency and a large air space, are a good choice. If the separation distance is large enough, these can be more effective than a single concrete panel. In separately supported structures, either wood or metal studs yield the same results. Offsetting or staggering studs, which are already on separate base plates, is not necessary.

In single-stud construction there is a more limited range of options available. With wood studs the two panels are rigidly attached by means of the line connections. The addition of multiple layers of drywall is only somewhat effective. A resilient attachment provides some decoupling, though not as much as a separated stud. Metal studs, because they are inherently flexible, can also provide significant decoupling. Resilient supports can be helpful in decoupling gypboard layers on either side of a wood stud or floor joist. Resilient channel must be properly installed so that the screws do not short circuit. Channels applied directly over layers of gypboard or other panel materials are ineffective due to bridging by the trapped air pocket. Products that can be attached only on one side are preferred over hat-shaped channels, which can be attached on both sides. Resilient channels are not recommended for party walls since they are not suitable for the mounting of bookshelves or heavy pictures. When applied to double stud and lightweight metal stud walls, resilient supports do not significantly increase the sound transmission loss since the structures are already isolated.

Party Walls

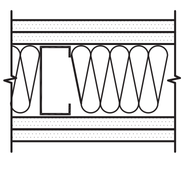
The selection of a party-wall construction should be based on the level of quality and the ultimate use of a given development. An example of party wall construction for minimum-quality construction is shown in Fig. 15.2. The minimum-quality construction consists of two layers of 5/8” (16 mm) drywall on each side of staggered 2 × 4 (38 × 89 mm) studs set

FIGURE 15.2 Minimum-Quality Party Walls



Staggered Wood Stud Wall
2 x 4 (50 mm x 100 mm) Studs on a 2 x 6 (50 mm x 150 mm) Plate
2 Layers 5/8" (19 mm) Drywall Each Side
R-11 Batt Insulation

125	160	200	250	315	400	500	630	800	1 k	1.3 k	1.6 k	2 k	2.5 k	3.2 k	4 k	STC
35	39	45	45	49	49	52	53	54	55	56	57	54	50	53	57	53



Metal Stud Wall
3 5/8" (90 mm) Metal Stud
2 Layers 1/2" (13 mm) Drywall Each Side
R-11 Batt Insulation

125	160	200	250	315	400	500	630	800	1 k	1.3 k	1.6 k	2 k	2.5 k	3.2 k	4 k	STC
40	44	46	48	52	56	59	58	59	59	62	63	62	58	52	57	56

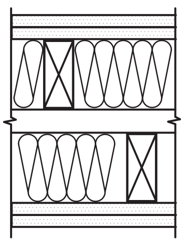
on a 2 × 6 (38 × 140 mm) wood plate. An alternative to staggered studs would be the use of a light-gauge 3 5/8" (92 mm) metal stud. The wall should have 3 1/2" (90 mm) fiberglass batt insulation having a thermal rating of R-11 in the air space. The staggered-stud wall rates an STC 53 while the metal-stud wall rates an STC 56 (CONC, 1981) with double 1/2" (13 mm) drywall. Generally a wall with two layers of drywall each side is preferable to one with only one layer even when the stud configuration yields comparable STC ratings. The small advantage in using mismatched drywall thicknesses in low-rated party walls (< 55 STC) is probably not worth the confusion it produces in having two thicknesses of drywall on the job site.

For medium-quality construction the first wall shown in Fig. 15.3 is a good choice. It consists of two layers of 5/8" (16 mm) drywall on each side of separate 2 × 4 (38 mm × 89 mm) wood or 3 5/8" (92 mm) metal studs separated by at least 1" (25 mm). There are two layers of R-11 fiberglass batt in the airspace. This wall has achieved an STC 63 in a laboratory test (CONC, 1981).

In high-quality construction projects the triple-panel wall shown in Fig. 15.3 has been used successfully. It consists of two layers of drywall, one 1/2" (13 mm) and the other 5/8" (16 mm) thick in the outside of separate 2 × 4 (38 mm × 89 mm) studs. On the inside of one set of studs are three layers of drywall: two 5/8" (16 mm) and one 1/2" (13 mm) thick. The layers are spot laminated and screwed together as described in Chapt. 9. There is R-11 fiberglass insulation in the air cavities. The STC test data shown are for a similar wall cited in Fig. 10.11, which was tested by Sharp (1973). The wall shown here will test a few points lower since the panels are not point mounted.

FIGURE 15.3 Medium- and High-Quality Party Walls

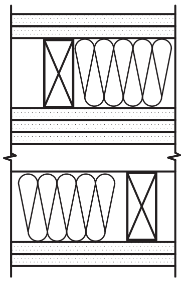
Medium Quality Party Wall



Double Wood Stud Wall
2 x 4 Studs Separated by a 1" Gap
2 Layers 5/8" Drywall Each Side
2 Layers R-11 Batt Insulation

125	160	200	250	315	400	500	630	800	1 K	1.3 K	1.6 K	2 K	2.5 K	3.2 K	4 K	STC
41	46	50	55	58	59	61	62	64	67	69	70	67	66	68	69	63

High Quality Party Wall



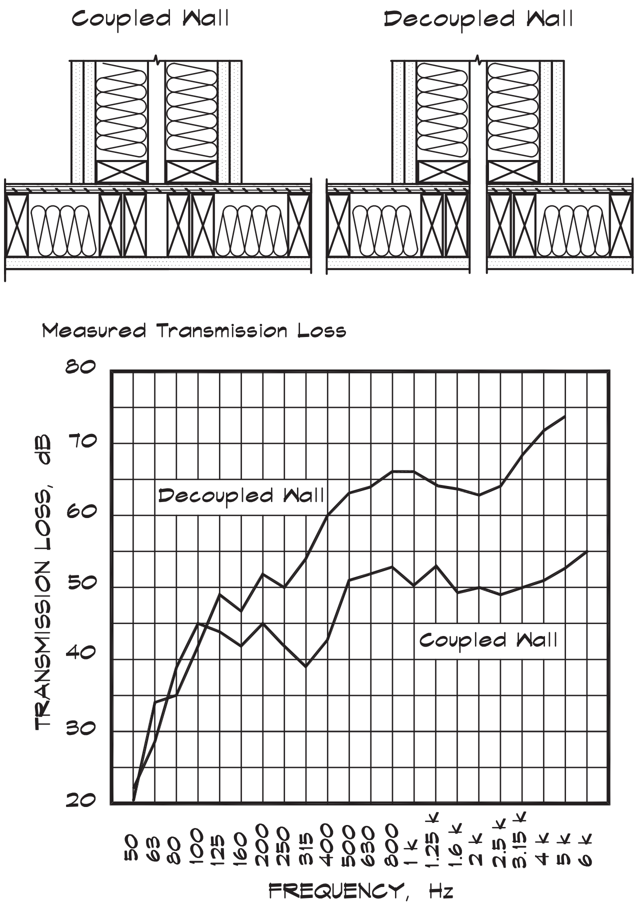
Double Wood Stud Wall
2 x 4 Studs Separated by a 1" Gap
Outside Layers 5/8" + 1/2" Drywall
Inside 5/8" + 1/2" + 5/8" Drywall
All Layers Spot Laminated at 24" OC and Screwed to Studs - 3" Batt Insulation in all Cavities

125	160	200	250	315	400	500	630	800	1 K	1.3 K	1.6 K	2 K	2.5 K	3.2 K	4 K	STC
53	56	60	66	70	75	78	80	78	79	83	83	84	87	88	89	76

Structural Floor Connections

In certain cases there can be significant flanking of a wall through structural connections such as a floor diaphragm. In wood-frame buildings there are requirements that there be a fire stop between wall studs or joists supporting a floor. In earthquake country there are also requirements that the building have adequate stability to withstand vibration-induced lateral motion. In many cases this stability is provided through a plywood diaphragm, which runs continuously from floor to floor beneath a sound rated partition such as a party wall in a multifamily residence. Craik, Nightingale, and Steel (1997) published a study of the flanking due to the presence of several types of fire stops: wood, metal, drywall, and safing (no connection). Their calculations (Craik, 1996), which used statistical energy analysis, assumed that the floor and wall could be modeled using four plates, one for each side of the wall and one for the floor on each side, with only a moment connection between them. Both calculated and measured results were reported. The measured results are summarized in Fig. 15.4. Note that the wall has a double stud with double 1/2" (13 mm) gypsum board, a 1" (25 mm) air gap, and two layers of batt insulation. The floor was constructed of a single layer of 5/8" (16 mm) plywood.

FIGURE 15.4 Effects of Structural Decoupling (Craik, Nightingale, and Steel, 1997)



The results show that there can be significant flanking due to the structural path through the floor when there is continuous plywood. In fact, the calculations indicated that for coupled structures the most important noise path is from the source room into the floor, through the diaphragm, into the adjacent floor, and into the receiving room. Improvements can be obtained by separating the two sides and by using a thin sheet metal or safing fire stop and by increasing the mass of the floor structure through the use of a concrete topping layer or by the installation of a floating floor system. Horizontal fire stops in double stud party walls can be achieved with drywall, which is attached only to one side. On the opposite side the gap between the drywall and the stud is minimized and stuffed with safing.

In concrete-slab construction the high mass of the floor helps block the room-floor-floor-room path. In wood construction a continuous diaphragm may be required for structural reasons, but here concrete topping slabs increase the floor mass and help decrease the floor transmission path. Metal straps may provide the coupling required by structural or earthquake requirements, while still providing a significant impedance mismatch.

Flanking Paths

In party-wall construction there can also be nonstructural flanking paths. When double drywall is used as a surface material, the joints on the second layer should be staggered with respect to the first layer. At the corners, layers should be overlapped and all joints must be premudded before taping. When this is not done a gap can remain between the two layers of drywall, which is covered over only with drywall tape.

At the base plate, the gap between the drywall and the floor should be caulked with a nonhardening caulk. Base plates should not be completely sawed through to accommodate piping. This is important because the drywall needs a continuous backing to seal against. It is more important to caulk under the drywall than it is to caulk under the bottom plate. The principal reason for caulk under the bottom plate is to provide blockage when the lumber is warped; however, this path should also be blocked by caulking the drywall. The addition of a caulked wood base strip along the bottom of the drywall helps to close off the gaps under the drywall.

Blocking headers, located above the top plates of the wall framing, should be doubled and joints between the headers and the joists should be kept tight. This prevents sound, which makes its way into the ceiling cavity, from migrating into an adjacent unit by way of the joist space.

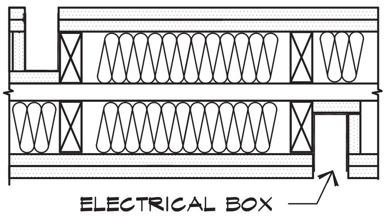
Where bathtubs and showers are located on a party wall they must be installed so that the integrity of the wall is not compromised. This means that the drywall (or green board) must be continuous behind tubs, showers, and other wall-mounted fixtures such as lavatories. Party walls should not be cut out to accommodate medicine cabinets or other surface-mounted millwork.

Drywall must also be continuous behind stairwells. Party wall framing should not provide structural support for stair risers. Even with double stud walls and carpeted stair treads, footfall noise on stairways can be audible when the stair framing is structurally attached.

Electrical Boxes

Once a decision has been made on the construction of the separating partition, care must be exercised to insure that the rating of the partition is maintained. One example, which we have already discussed, is through a hole or other area of reduced transmission loss in a wall.

FIGURE 15.5 Treatment of Electrical Boxes in Rated Walls



These can be gaps in and around electrical boxes or simple cutouts in walls for telephone, computer or television cabling. Too often wiring is run freely in walls and not contained in conduit and metal boxes. When this occurs the plastic electrical wall plate becomes the weak part of the structure and can lead to a degradation of the performance of the partition. Even a small opening such as a 1/2” (13 mm) emt conduit between two 2 × 4 electrical boxes can significantly degrade the transmission loss.

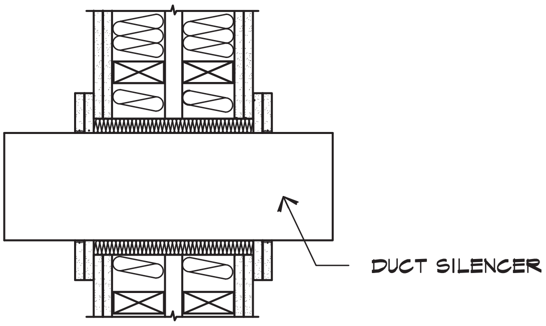
It is good practice to enclose all wiring, including low voltage computer, telephone, and cable TV wiring, that is located in sound-rated partitions, in metal boxes and conduit. Where these boxes penetrate the wall surface the openings between the drywall and the box should be sealed with caulk or plaster. Electrical boxes should be offset 24” (0.6 m) or two studs when they are located on opposite sides of a wall. Figure 15.5 illustrates this principle. The backs and sides of the boxes should be buttered with plaster, wrapped with drywall, or sealed with clay pads to attenuate sound penetration out of the back of the box. Wrapping with drywall is preferred since clay pads can peel away from the box over time. A 1/2” (13 mm) sheet of drywall, which spans the stud bay containing the electrical box from the base plate to a height 12” (300 mm) above the electrical box, can be used in place of wrapping. Batt insulation must be placed within and behind the drywall cavity. At the point where the electrical boxes penetrate the drywall, all gaps between the outside of the box and the drywall must be sealed with drywall mud or caulk.

Wall Penetrations

Where plumbing pipes are located in party walls (this is not recommended), penetrations should be avoided. If a pipe must penetrate a party wall a resilient escutcheon or caulked opening should be used; however, these openings can compromise the sound isolation over time. When water flows through a pipe it can move the pipe around, due to the forces produced by the fluid as well as thermal expansion and contraction. Pipe movement tends to open up the hole at the penetration even when it is caulked. Piping penetrations on opposite sides of a party wall should be offset by 24” (610 mm). Piping to adjacent units should be separate and the piping should only be supported on the studs on the side of the wall whose unit it serves. Plumbing piping or rigid conduit connected to the structure on both sides will short circuit the stud separation. Sufficient space must be allowed for the passage of waste piping so that it does not make contact with the panels or support structure on either side. When there are back to back pipe penetrations in a double stud party wall, a layer of drywall should

FIGURE 15.6 Treatment of Rated Wall Penetrations

When a large duct or pipe penetrates a rated wall, the opening is oversized by about 1" (25mm) and filled with fiberglass board. The ends are capped with drywall closely fitted to the penetrating body and caulked. Use the same number of layers as are on the wall.



be installed on the inside face of a stud behind one penetration, a stud space wide extending 18” (457 mm) above and below the penetration.

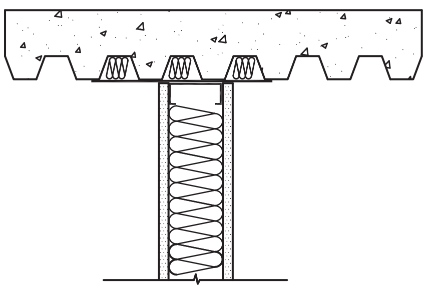
When a duct or pipe penetrates a rated separation the penetration must be treated so as to retain the rating of the partition. If the penetrating element is a large pipe or duct, as shown in Fig. 15.6, a hole in the wall is cut, leaving about a 1” (25 mm) gap that is filled with fiberglass board. The opening is then sealed off with the same number of layers of drywall as the original wall surface and the remaining gap is caulked. In the case of a pipe penetrating a concrete floor, the opening above and below the fiberglass can be filled with a sealant.

Holes

At the top of a wall the attachment of a stud wall to a metal deck can be tricky. Sheet metal plates or rubber filler strips can be used to close off the openings above the top track as shown in Fig. 15.7. Where nested tracks are employed to allow for floor movement, the outer layers of drywall should overlap the inner track and be caulked against the floor plate. When a wall

FIGURE 15.7 Wall Connection at a Metal Deck

A wall butting up against a metal deck should be attached to a sheet metal plate, typically 16 ga. The webs are stuffed with safing or prefabricated neoprene strips.



parallels the deck webs, a plate of 16 Ga sheet metal with safing in the cavities will close off the path above the wall. A wall that runs perpendicular to the webbing can be topped with a wide sheet metal plate, neoprene inserts, or cut drywall. Walls that lie at an oblique angle to the webbing can also be sealed with a wide plate with the cavities stuffed with safing.

15.3 PARTY FLOOR-CEILING SEPARATIONS

Noise and vibration problems encountered in floor-ceiling systems fall into the four categories discussed in Chapt. 12: airborne noise, structural deflection, footfall, and floor squeak. Floor vibration and vibration isolation of mechanical equipment are separate topics, which were discussed in Chapt. 11.

Airborne Noise Isolation

Airborne noise isolation in floors follows the same principles and is tested in the same manner as airborne isolation in walls. As was the case with wall transmission, the isolation of airborne noise such as speech is well characterized by the STC rating. STC tests are done by placing the noise source in the downstairs room to insure vibrational decoupling between the loudspeakers and the floor-ceiling being tested. The ratings shown in Table 15.4 apply to floor-ceiling separations just as they applied to walls, but the choice of floor systems is greater.

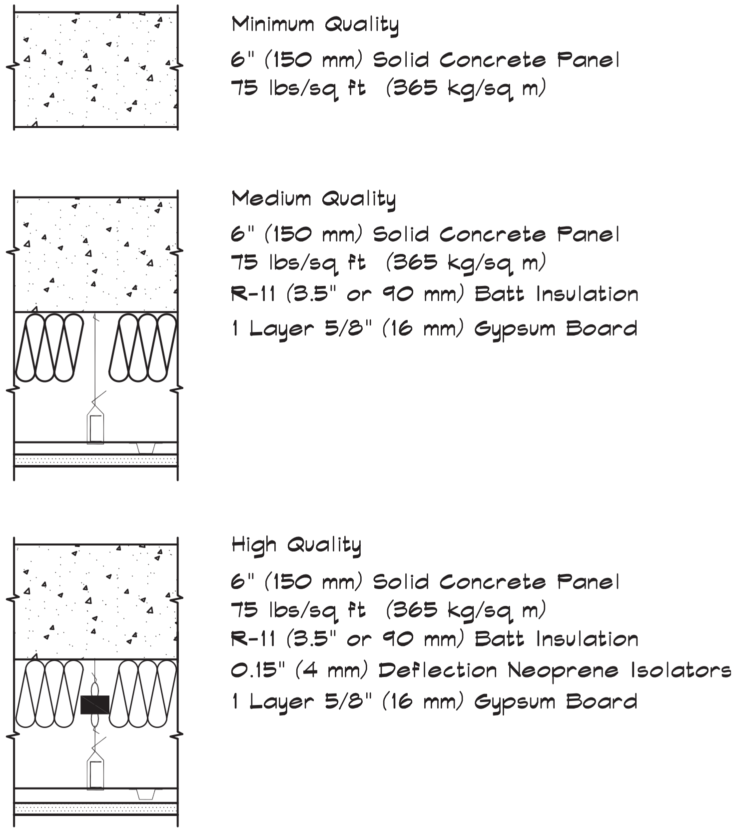
Highly rated floor-ceilings combine a high-mass floor with a large separation between panels as in a double panel wall system. Ideally the two panels should be structurally decoupled either by separate structural supports or by means of a resiliently hung ceiling or floating floor. At low frequencies a high structural stiffness is desirable to minimize the plate deflection.

A simple concrete slab of sufficient thickness can provide a good floor-ceiling. A 6” (152 mm) thick slab has an STC rating of 55 and is sufficient by itself for a minimum quality floor. Six-inch concrete slabs with a wire-hung drywall ceiling can provide sufficient isolation for airborne noise to be used in medium-quality construction. For high-quality construction even with concrete slabs a drywall ceiling suspended from neoprene isolators is preferred. Figure 15.8 shows some examples of concrete floor-ceiling systems.

In wood construction the structures are light and stiff. The problem with wood floors for airborne noise isolation is in achieving sufficient mass. Lightweight-concrete fill weighs 110 to 115 lbs/cu ft (540–560 kg/sq m) and should be poured to a thickness of at least 1.5” (38 mm). A hard concrete fill (140–150 lbs/cu ft or 685–735 kg/sq m) is preferred; however, the structural system must be designed to accommodate the additional weight. Figure 15.9 gives examples of wood floor-ceiling systems suitable for various levels of quality in multifamily dwellings. Note the increasing thickness of plywood subflooring.

Composite floor-ceiling systems fall somewhere between wood and concrete. A composite floor can be constructed using a 5” (127 mm) lightweight concrete fill poured into a webbed sheet metal deck with a suspended ceiling below. With this configuration a drywall ceiling is required even for the minimum design standard. Several designs are shown in Fig. 15.10. Note that there is no structural support provided by the lightweight concrete or the sheet metal pan. The structural floor stiffness is due to the supporting beams. When these beams have a long span, floor deflection can be a greater problem than noise transmission.

FIGURE 15.8 Concrete Floor-Ceiling Assemblies

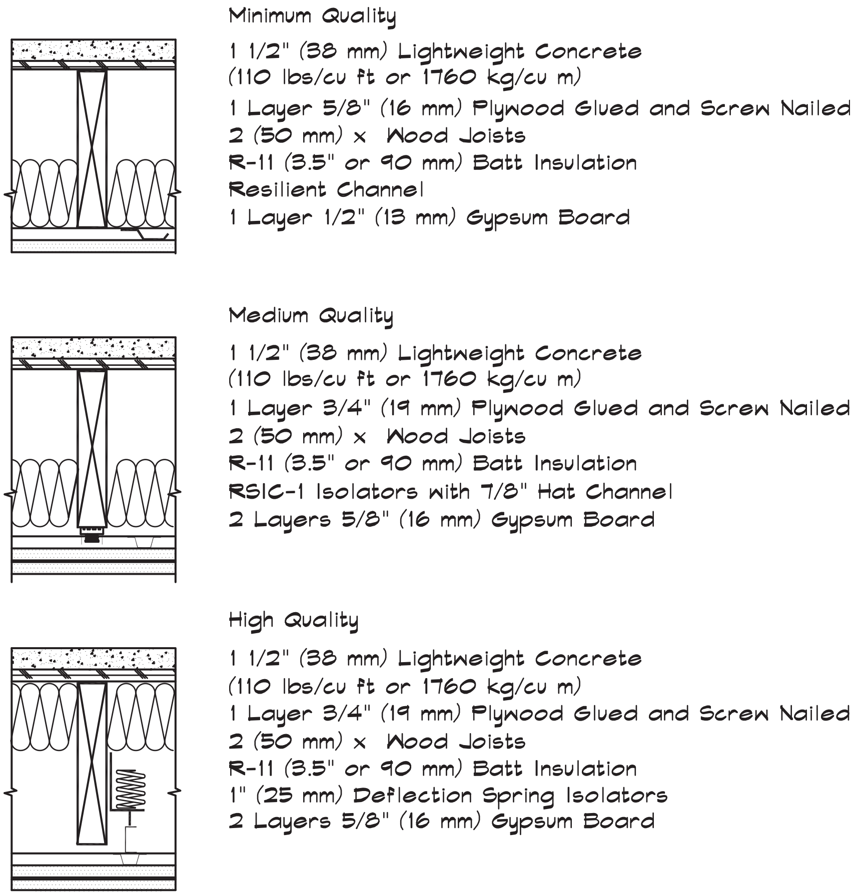


Structural Stiffness

The achievement of a high IIC rating in a given floor-ceiling system does not guarantee that noise will not be a problem or that the sound of walking will not be audible in the units below. The IIC test measures the reaction of a floor system to the impact of a series of 1.1 lb (0.5 kg) weights dropped on the surface. Although this may model the noise of a heel tap, it does not represent the full effect of the loading and unloading under the weight of a walker. When a person steps or even stands on a floor, it will deflect under the static and dynamic load of his weight, as we discussed in Chapt. 12. If the underside of the floor is exposed to the room below, a sound generated by this motion will radiate directly into the receiving space. Noise generated by floor deflection sounds like low-frequency thumps, whereas heel clicks have a spectral character largely dominated by the high frequencies.

Three mechanisms are available to improve this condition: 1) increase the stiffness of the floor system, 2) increase the structural damping, and 3) increase the vibrational decoupling between the floor and the ceiling. In concrete structures both the stiffness and damping increase with slab thickness. For the 6” (152 mm) concrete slab required to achieve an STC of 53-55 structural deflection is rarely a problem for moderate spans. In wood structures the most common type of minimum quality construction consists of 1.5” (38 mm) lightweight concrete on plywood on joists with ceilings of drywall on resilient channel. This construction

FIGURE 15.9 Wood Floor-Ceiling Constructions



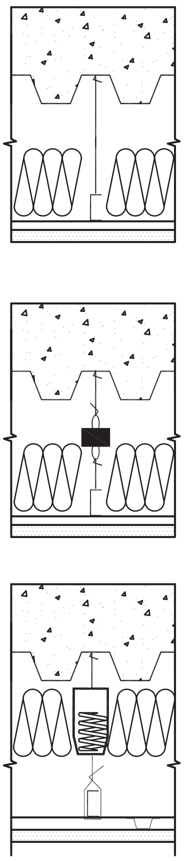
can transmit considerable low-frequency noise, since for normal joist lengths the deflection of the resilient channel is not sufficient to overcome the deflection of the joists.

In wood construction both stiffness and damping can be increased by using the stepped blocking shown in Fig. 12.24. The blocking works for several reasons. The first is the damping added by the moment connection provided by the glued faces and end nailing. Second the stiffness is increased by building the equivalent of another beam in the middle of the joist system. The third effect is additional load spreading, which distributes a point load over several joists and helps increase the composite floor stiffness. Stepped blocking is more effective than doubling joists or reducing joist spacing, although the two can be combined to good effect. When prefabricated truss joists are used, a spacer plate must be installed as in Fig. 12.28. Stepped blocking should be located at the mid-span in joists having a length of between 12 to 18 feet (3.7—5.5 m) and at the one-third points in joists greater than 18 feet.

Structural Decoupling

If a floor-ceiling system is not a monolithic slab, it generally includes an independently supported ceiling, which may be isolated vibrationally from the structure. In concrete

FIGURE 15.10 Steel Deck and Concrete Floor-Ceiling Constructions



construction the most common support system is hanger wires at 4' (1.2 m) on center wrapped around 1 1/2" (38 mm) carrying channel (black iron) to which 7/8" (22 mm) metal furring channels (hat channels) are wire-tied. This system provides some isolation because it uses a point connection (Chapt. 9) rather than a line connection. It can be improved further by utilizing vibration isolators either in the form of neoprene hangers or steel spring isolators cut into the hanger wires.

In wood structures a common type of structural decoupling is resilient channel. At high frequencies resilient channel can provide some improvement to the structural isolation; at very low frequencies, however, it is not particularly effective. Several different kinds of resilient channel are available on the market, some of which are shown in Fig. 15.11.

When resilient channel is installed improperly, it is ineffective, so the manufacturer's installation instructions must be followed closely. A z-shaped channel is one of the easiest to install, but screws that are too long can still short out the decoupling as shown in Fig. 15.12. Z-shaped resilient channels should be installed with the open side up when they are attached to studs so that the weight of the applied drywall pulls the channel open and away from the stud.

Hat-shaped resilient channels must be installed so that there is an attachment screw on only one side of the flange. Each screw attachment alternates from one side to the next.

FIGURE 15.11 Types of Resilient Channel

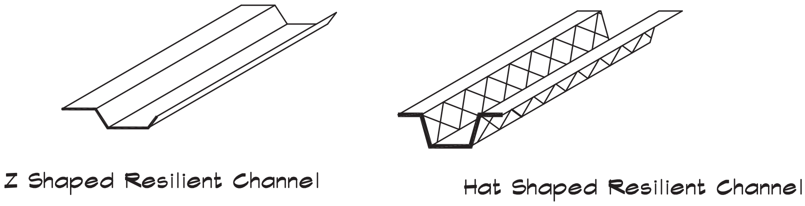
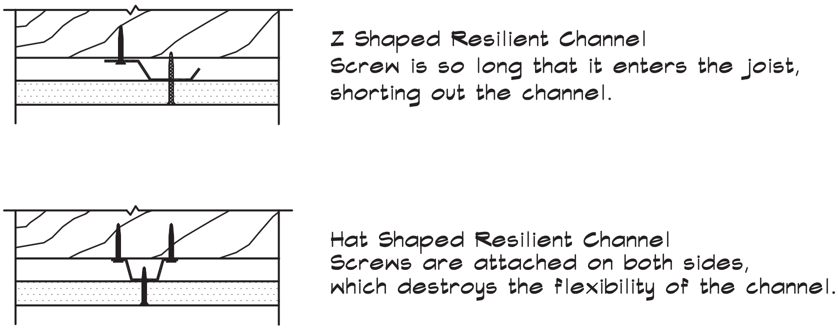


FIGURE 15.12 Improperly Attached Resilient Channel

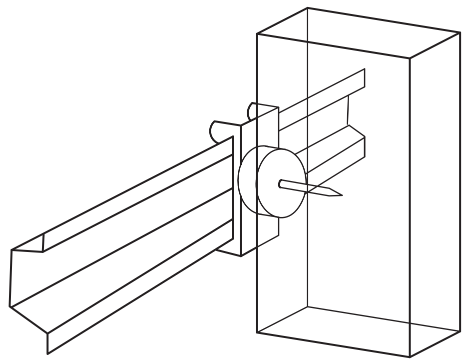


If it is screwed to a joist on both sides the hat channel is not free to deflect and is ineffective. The side webbing of hat-shaped resilient channels have openings to reduce their stiffness; however, they are still too stiff to provide appreciable isolation if they are screwed to the joists on both sides.

Neoprene mounts, which include a clip to support hat channels, recently have become available. These give somewhat better floor isolation than resilient channels (STC 61) and can support a double layer of drywall. They are installed on 24” (0.6 m) centers in one direction and at twice the joist spacing (typically 32” or 0.8 m) in the other. They provide the advantages of a resilient point-mount support along with ease of installation. A sketch is included in Fig. 15.13.

The most effective structural decoupling in wood floor-ceiling systems is a resiliently supported ceiling hung from spring hangers shown in Fig. 12.3 (STC 73). Note that the hangers are located high on the joist to preserve as much ceiling height as possible. Spring hangers are more effective than a ceiling supported on separate joists since with the latter system there is still the possibility of structural transmission through the joist supports. When a spring-hung ceiling is installed, unless the springs are precompressed, it will drop by the amount of the hanger isolator deflection. Hence the ceiling drywall must not extend beyond the top of the wall drywall, or else its weight will be supported by the walls and the ceiling will bow. An example of a proper installation is given in Fig. 12.4. Once the ceiling has come to its final elevation the gap between the ceiling and wall material may be caulked. Molding or other trim pieces then can be added since they are nonbearing.

FIGURE 15.13 RSIC Resilient Point Mount Supports (Pac International)



Spring precompression can minimize the actual deflection; in practice, however, this is somewhat tricky since the final load must be determined carefully. Springs are located at 4’ (1.2 m) on center, and if they support 16 sq. ft. (1.5 sq m) of ceiling, at 5.5 lbs/sq ft (27 kg/sq m), they will each carry about 90 lbs (41 kg). A spring located along an edge will carry a little more than half that load, and one in a corner somewhat more than one quarter. In irregularly shaped ceilings or one with coffers and light fixtures the loading is more complex. It is prudent to have springs of several different sizes at a job site in case the odd hanger is needed. When stepped blocking and a resiliently hung ceiling are used in combination, the black iron can run parallel to the joists just below the blocking. The hat channels run perpendicular to the joists just below them. When the drywall is installed its weight will pull the hat channel away from the joists so it does not touch.

Floors should be structurally decoupled laterally as well as vertically. Joists should not be run continuously across a party wall separation but should be supported on the nearest side of the party wall framing.

Floor Squeak

Creaking floors are caused by the relative motion of wood on wood or nails rubbing against diaphragms, joists, or metal joist hangers. One common cause are shiners, as they are called—nonbedded nails that lay alongside a joist and rub as the floor structure deflects. These must be removed before any lightweight or other concrete fill is poured.

Another cause is unevenness in the top surface of the joists, either due to imperfections in the wood or in the case of joist hangers, to differences in the joist level, which allows motion of the floor diaphragm against the nails. Gluing diaphragms to the joists, prevents much of the panel motion and increases damping. Joists can also be shimmed at the hanger to assure even floor support. In tongue and groove flooring the individual planks can move relative to one another. Gluing or applying paraffin to the plank edges helps prevent this cause of squeak.

In some cases subflooring, made of wood strands bonded together with a resin material, has been found to contribute to floor squeak. When these materials deflect they rub against the nails, which powders the binder and opens up a small hole around the nail, which in turn loosens the grip of the nail on the board. This effect can be offset somewhat by gluing under the flooring and using a gripping ring shank nail. Ring shank nails are recommended for nailing all wood diaphragms since they provide some additional grip on the plywood. To repair existing wood floors, screws can be added to cinch down the flooring to the joists and reduce panel movement. Glue should be applied from below along the top edges on both sides of the joists.

Floor Coverings

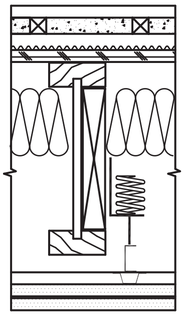
It is relatively easy to achieve high impact insulation class ratings by using carpet and pad. Medium quality ratings are achievable with a cushioned or padded vinyl floor surface. It is where hard materials such as quarry tile, marble, sheet vinyl, or hardwood floors are used that low impact ratings are encountered. As an example Fig. 12.11 shows the results of several IIC tests carried out on a minimum quality lightweight concrete and wood floor-ceiling construction. The ratings range from an IIC 76 for a heavy carpet and pad to an IIC 38 for exposed concrete.

Where hard surface floors are desired a spring isolated ceiling or concrete floating floor are usually required to achieve medium quality. Figure 12.12 gives an example. Thin layers of resilient material such as fiberglass board, cardboard-like materials, and wire mesh mats can raise the IIC ratings modestly, three to five points, but seldom provide sufficient deflection to achieve the impact isolation necessary for condominium construction. A number of products are commercially available, which are intended as a resilient underlayerment for hard-surfaced flooring. A typical construction consists of a plywood diaphragm on joists with the underlayerment above followed by a spanning cementatious board with tile set into a mortar bed on top of that. When combined with a drywall ceiling supported on resilient channel these constructions can provide IIC ratings a few points above minimum code. At this rating footfall noise is still clearly audible, and although the system may pass the minimum code requirements, it is unlikely to meet a condominium buyer's reasonable expectation of quality. The general failing of these materials is that they are so thin (1/4–3/8" thick) that they provide very little deflection. Hence their natural frequency of vibration is relatively high. When combined with the reduced impedance of the support system below due to the lack of lightweight concrete, their overall effectiveness is modest. Figure 12.22 shows the test results using a mesh mat underlayerment below a tile floor, which has an IIC 53 rating, barely above the minimum code.

The preferred floor covering in multifamily dwellings is carpet and pad. Hard surface floor coverings such as marble tile, quarry tile, and hardwood flooring are not recommended unless a spring-supported ceiling and a resilient floating floor are used. Even in these cases high quality IIC ratings are difficult to achieve. Figure 15.14 gives an example of a hardwood floor, which has achieved a field IIC rating of 69. The floating floor rests on 1" (25 mm) thick, 20 durometer dimpled rubber mats. The ceiling is supported on 1" deflection spring isolators. A similar installation with tile would likely have a lower rating. Note that the overall thickness of this construction is 18" (460 mm).

Where the appearance of wood or tile is desired, a hard surface can be used in non-walking areas such as within 1 to 2 feet (0.3–0.6 m) of a wall with carpet installed where walking traffic occurs. In kitchen and bathroom areas vinyl tile over a soft backing material such as a 20 durometer, 11/16" (17 mm) thick, dimpled rubber mat can provide reasonable IIC ratings, particularly when combined with a point-mounted resiliently suspended ceiling.

FIGURE 15.14 Double Isolated Wood Floor –Ceiling (Adams, 2002)



100	125	160	200	250	315	400	500	630	800	1 K	1.3 K	1.6 K	2 K	2.5 K	3.2 K	FIIC
47	49	48	48	49	47	41	38	36	33	30	29	28	27	25	20	69

15.4 PLUMBING AND PIPING NOISE

Noise from plumbing and piping is one of the most important causes of dissatisfaction in residential structures. It has become much more noticeable with the unfortunate use of plastic pipe in waste stacks, but it can also be caused by excessive flow velocities in supply pipes and be exacerbated by poor isolation. Plumbing and piping noise frequently originates with turbulent flow in pipes and fixtures and is transmitted primarily through vibrational coupling to the building structure and into the occupied spaces. Several other noise generation mechanisms are present in plumbing including cavitation, water hammer, vibrational transmission of pump or other mechanical noise, and water impact or splash noise; however, noise produced by turbulent flow is the primary source.

Supply Pipe

For normal velocities, the flow of water in straight residential supply pipes can be considered to be turbulent. In turbulent flow, regions of highly varying pressure are created, which transfer to the walls of the pipe and from there to the structure. Although turbulence is present in straight pipe, it is mainly caused by valves, fixtures, elbows, and constrictions. Several factors influence the noise generated by a supply pipe. The first is the velocity of flow within the pipe itself, which affects the amount of noise created by any valves or fixtures. The second is the way in which the pipe is attached to the structural framing, both to the structure and to the surface material.

Measurements have been made by Van Houten (1979), who investigated both these factors. Figure 15.15 shows his experimental setup. The test apparatus consisted of a double stud wall with one layer of drywall on each side and supply piping through the studs on the far side of the wall. Pressure was regulated with a valve and the pipe was terminated in a flexible hose. This is perhaps not the most realistic test condition since in a real situation the flow regulating fixture would probably be remotely located.

The attachment methods are sketched in Fig. 15.16. When pipes are routed through holes drilled in a series of studs it is rare that each hole is perfectly aligned with its neighbor. Consequently the pipe, which courses through these holes, will lie closer to the stud on one side or the other at each penetration. Isolators that are wedged into the holes will be pinched on the close side or will be loose if the holes are oversized. The preferred mounting method is to wrap felt around the pipe, outside the hole, and to band it with plumbers tape. This

FIGURE 15.15 Piping Noise Test Configuration (Van Houten, 1979)

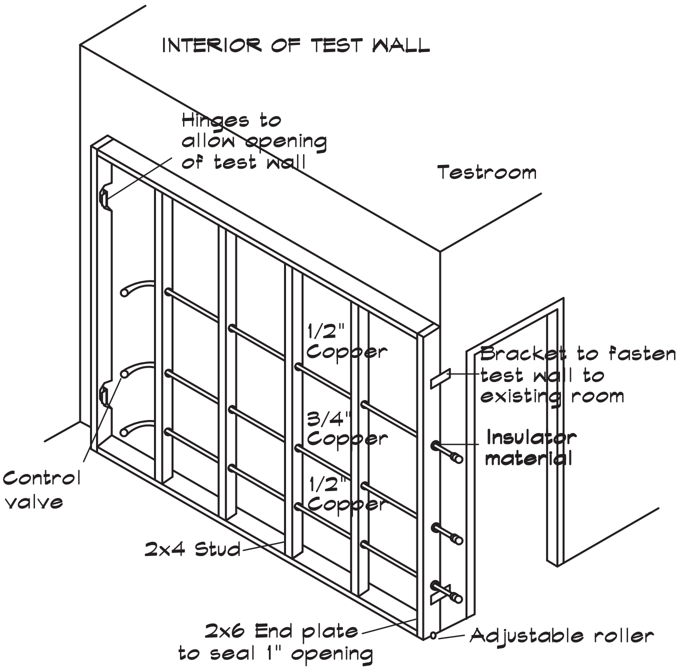


FIGURE 15.16 Pipe Mounting Methods and Descriptions (Van Houten, 1979)

MOUNTING	METHOD OF PIPE MOUNTING	ILLUSTRATION
A	Wood wedges, two wood wedges forced between the pipe and stud	Wood
B	"J" Hook nail ons, Type 3/4" E.M.T. nail on at each pipe penetratio of stud	Nail-on
C	Felt packing, 1/2" thick carpet felt packed between the pipe and stud	Felt
D	Pipe insulator, insulator without foam insert	Insulator
E	Pipe insulator, with polyethylene foam insert	Polyethylene foam
F	Rubber bands	Rubber bands

TABLE 15.7 Sound Levels Transmitted by Supply Piping, dBA (Van Houten, 1979)

Mounting Description		Supply Pressure			
1/2” Copper Water Pipe		30 psi	45 psi	60 psi	70 psi
A	Wood Wedges	50	54.5	56	57
B	J Hooks	50	54.5	56	
C	Felt Packing	44.5	48.5	49.5	
D	Plastic Pipe Insulator	51.5	55.5	57.5	
E	Foam Pipe Insulator	40.5	43.5	44	
F	Rubber Bands	35.5	35.5	31	
3/4” Copper Water Pipe					
A	Wood Wedges	47.5	51.5	52.5	
C	Felt Packing	42.5	45.5	46	
E	Foam Pipe Insulator	39.5	42.5	43.5	

allows the pipe to move without making contact with the stud. In general piping should be free to move slightly but must not touch the structure or the drywall. When a pipe cannot move, it indicates that it is being rigidly constrained, either by the structure or by an isolator that is overly compressed.

For a specific diameter pipe, the noise generated at a given back pressure is illustrated in Table 15.7. The data show the dependence of the noise level on pressure and mounting for 1/2” (13 mm) and 3/4” (19 mm) diameter pipe. Clearly there is substantial benefit to lower pressures; however in practice, pressures of 45 psi are usually required to maintain adequate flow. High pressures, on the order of 60 to 70 psi, are not necessary and should be avoided.

The data shown in Table 15.7 illustrate that there is little difference in noise level among the different types of rigid connections. Wood wedges, J hooks, and hard plastic pipe supports all lead to high levels even when contained in a double stud wall with batt insulation. There is substantial improvement afforded by resilient supports and the softer the mount the greater the isolation, although considerable effort is required to achieve satisfactory levels. This may be due in part to the setup of this experiment with the control valve upstream of the test section located close to the wall. It emphasizes the importance of keeping plumbing fixtures off party walls.

Table 15.7 lists the pipe diameter, mounting method, and back pressure as independent variables. In most real situations the flow volume is fixed by the downstream conditions. For example, if a pipe serves a shower nozzle the conditions at the outlet determine the flow rate. Upstream the piping can be sized to control the fluid velocity and thus the local turbulent noise. Careful selection of valves and nozzles can help reduce noise generation at the termination.

Intrusive noise due to plumbing and piping should be limited to the levels set forth in Table 15.8. These apply to any occupied space within a dwelling unit, including bathrooms. As we have previously discussed, as the level of quality increases the tolerance for neighbor-generated intrusive noise decreases.

In order to control turbulence-generated noise in supply piping a combination of several steps is required. First, the line pressure in the supply pipes should be below 60 psi. Second,

TABLE 15.8 Maximum Intrusive Noise Levels Due to Plumbing

Classification	SPL (dBA)
Minimum Quality	35
Medium Quality	30
High Quality	25

the pipes must be sized large enough that flow generated noise is kept to a minimum. Table 15.9 shows recommended pipe sizes and the maximum flow velocities and flow rates (Wilson, Ihrig & Associates, 1976).

A tub fills at a rate of about 8 gal/min so that a 1" (25 mm) pipe would be appropriate. A low-flow shower supplies water at about 3 gal/min so a minimum 3/4" (19 mm) pipe could be used. Where multiple fixtures are served the supply pipes should be scaled up accordingly. The larger pipe diameters allow local flow velocities to remain low even when it is necessary to neck down a pipe size to accommodate a valve or fixture. The third factor is wall construction. In walls containing piping that serves another unit, the wall surface should be a minimum of two layers of 5/8" (16 mm) drywall. There should be a full layer of batt insulation in all walls where supply, waste, or other fluid-carrying pipes are located.

The fourth factor, mechanical decoupling, is perhaps the most important. Piping must be physically decoupled from both support structure and from the wall surface. In party walls the piping should be supported only on the side of the wall that is served by the pipe. The type of resilient support is summarized in Table 15.10. Note that the isolation shown above is for water supply pipes. It is not required for vent stacks, fire sprinkler pipes, or gas pipes, although when vent stacks are rigidly attached to waste stacks they too should be isolated.

TABLE 15.9 Maximum Flow Velocities in Supply Pipe (Wilson, Ihrig & Associates, 1976)

Nominal Pipe Size (inches)	Max. Velocity (ft/sec)	Max. Flow Rate (gal/min)
1/2	1	1
3/4	2	3
1	3	8
1 1/4	3.2	15
1 1/2	3.5	22
2	4	42
2 1/2	5	74
3	6	138
3 1/2	6.5	200
4	7	277
5	7.5	467
6	8	720

TABLE 15.10 Vibration Isolation of Supply Piping

Nominal Pipe Size	Required Isolation Type	
(inches)	Horizontal	Vertical
1/2	1/4” Felt	1/4”Felt
3/4	3/8” Felt	3/8”Felt
1	3/8” Felt	3/8” Felt
1 1/4	3/8” Felt	3/8” Felt
1 1/2	3/8” Felt	3/8” Felt
2	1/2” Felt	WSW Pads
2 1/2	HN Hangers	WSW Pads
3	HN Hangers	ND Mounts
3 1/2	HN Hangers	ND Mounts
4	HS Hangers*	V Mounts*
5	HS Hangers*	V Mounts*
6	HS Hangers*	V Mounts*

*Nominal 1” deflection isolators

The details of the pipe isolation vary somewhat. For small diameters (< 2”) the pipe can be secured with a full wrap of plumbers tape around a 1/4” (6 mm) felt pad. Foam and plastic isolators are commercially available, but they must contain a sufficient thickness (1/4–3/8”) of foam or other isolating material to be effective. Hard-plastic mounts without soft inserts are ineffective. Neoprene in shear isolators can be effective in securing shower supply pipe as shown in Fig. 15.17.

With larger pipe sizes it may be more convenient to mount a number of pipes to a common structural frame, which is itself supported on neoprene mounts as Fig. 15.18 shows. Vertical riser pipes are held in place with a pipe clamp, which then rests on neoprene mounts or pads, as in Fig. 15.19.

In critical applications such as high-quality construction, it is sometimes necessary to wrap supply pipes with foam lead sheets where the pipes are located within walls or floor-ceilings of other occupied spaces, or where they are contained in the wall of a bedroom. Foam lead sheets consist of 1/4” (6 mm) foam adhesively attached to both sides of a 2 lb/sq ft (9.8 kg/sq m) lead sheet approximately 1/16” (1.6 mm) thick, which provides both vibration isolation and noise reduction. They can be cut to the appropriate size with shears and tied

FIGURE 15.17 Felt Isolated Shower Attachment

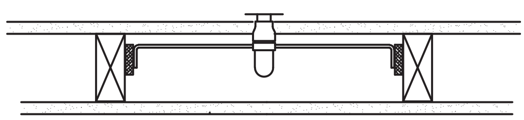


Figure 15.18 Resilient Multiple Pipe Support

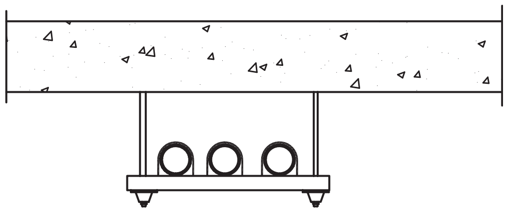
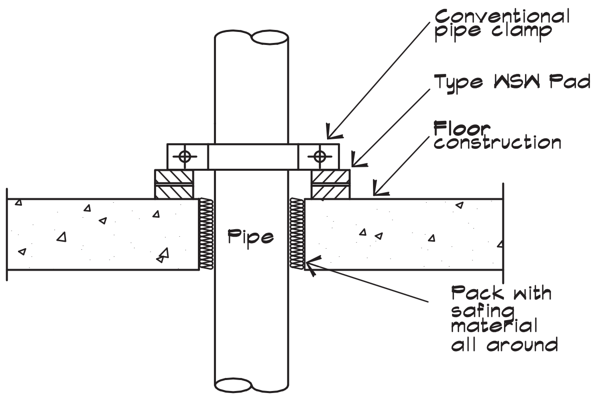


Figure 15.19 Floor Penetration Detail for Pipe Risers



with wires so that they completely encircle the pipe and overlap at least an inch (2.5 cm). Additional felt at points of support is not required for foam lead wrapped pipe.

Water Hammer

Water hammer is a shock wave, usually generated by the rapid closure of a valve, but occasionally caused by a pressure wave resonance within a pipe. In the case of an isolated occurrence, it produces a violent slamming, which physically moves the pipe and causes a loud banging noise. In the case of a resonance the passage of a shock wave back and forth results in a very loud low-frequency buzzing sound.

Water hammer creates a dramatic effect, which if allowed to continue, can result in damage to the pipe. Control is effected by exposing the fluid stream to a confined air pocket, which allows the high pressure shock to expand into a pressure release surface. These devices, called water hammer arrestors, contain a gas trapped in a flexible bladder that encircles the fluid or is contained in a separate branch on a threaded T-fixture. In residential structures such devices are very effective when mounted to the outlet pipe of the water heater and near any quick-closing valves, such as automatic sprinkler systems. Occasionally they may also be necessary to control resonances in long runs of pipe or near a particularly troublesome valve.

Waste Stacks

Waste stacks, which carry water and effluent from toilets and other fixtures, are a frequent cause of noise complaints, particularly when plastic (PVC or ABS) pipe is used. This lightweight pipe transmits annoying levels of noise when water flows through it. When a toilet is flushed upstairs and the water rushes through a plastic pipe, levels as high as 60 to 65 dBA have been measured in downstairs units. This is loud enough that it makes normal conversations difficult and is certainly a show-stopper for the party guests. The cause is the lightweight plastic material, which vibrates due to the turbulent flow created by the passage of the waste water, and any direct coupling of the pipe to the structure. Consequently plastic waste stacks should never be used in residential buildings or sensitive commercial structures such as offices, classrooms, hospitals, studios, or theaters even for short runs such as P-traps.

Instead of plastic, cast iron is the preferred material for waste stacks due to its mass. Even with cast iron problems may arise if the pipe is not properly isolated. Waste stacks must be vibrationally isolated just as supply pipes were isolated. The inherent mass of cast iron and the relatively slow fluid velocity makes the isolation requirements less stringent than similarly sized supply pipes. Vertical risers should be supported on type WSW neoprene waffle pads as shown in Fig. 15.19. Horizontal runs may be isolated with 1/2” (13 mm) felt or neoprene pads. Frequently waste stacks exceed 2.5” (64 mm) in diameter, and when they are wrapped with a felt isolation material the combination may not fit within a single stud space without binding. Thus it is prudent to allow at least a 2 × 6 stud for all walls housing waste stacks. This permits a neatly drilled round hole of sufficient size to allow the pipe to pass through the base plate or stud without touching the structure.

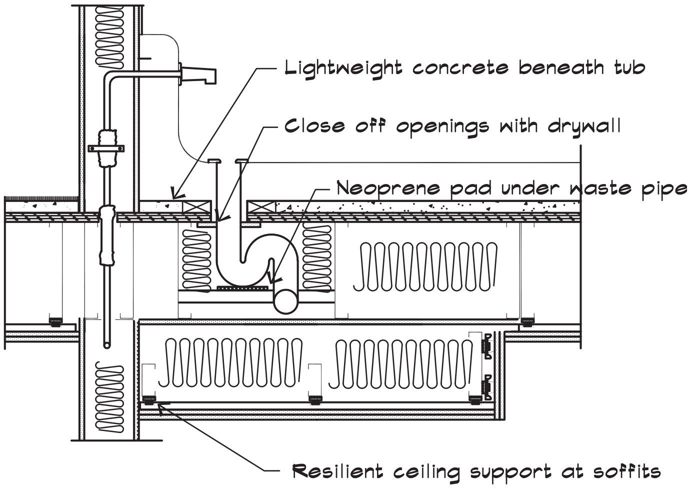
When treating an existing condition where plastic pipe has been used as a waste stack, noise levels have been reduced to inaudibility by decoupling the pipe from the structure, wrapping it with 2 lb/sq ft (9.8 kg/sq m) foam lead sheets, installing R-11 batt insulation in the airspace, and applying two layers of 5/8” (16 mm) drywall on resilient channel to the stud. In some cases the replacement of plastic pipe with cast iron pipe may be less expensive. Note that if the plastic pipe is replaced it should be removed completely for its entire length.

Tubs, Toilets, and Showers

Tubs, toilets, and showers should be installed over a floor-ceiling, which is equivalent to that constructed in the rest of the residence. In wood construction if the floor has lightweight concrete it should extend under the tub or shower. Where fiberglass tubs are installed, it is good practice to pour additional lightweight concrete around the bottom of the tub to add mass and damping.

Below the tub, where the piping penetrates the floor, builders sometimes leave a sizable opening in the floor for ease of installation. This must be closed for both acoustical and fire

FIGURE 15.20 Bathtub Installation Detail



code reasons using at least two layers of 5/8” (16 mm) drywall as in Fig. 15.20. Where the P-trap is supported on a crosspiece the pipe should rest on a neoprene waffle pad isolator consistent with its size.

Since the noise generated by supply piping is velocity dependent, low-flow devices like an aerated showerhead can reduce supply-pipe noise. Upstream noise from the pipe serving a toilet can be reduced by restricting the flow locally at the wall valve. Careful selection of quiet fixtures such as ball valves can prevent noise creation at a critical location.

Pump and Piping Vibrations

When a pump is located in a residential or other noise-sensitive structure the pulsations imparted to both the pipe and the driven fluid can create noise both by vibrational and airborne transmission paths. Control of pump vibrations begins with the location of the pump in a nonsensitive area such as a basement; however, it is not uncommon to find rooftop installations in large condominium complexes. Both the pump and the pipe must be properly isolated, beginning with a concrete housekeeping pad and inertial base such as that shown in Fig. 13.6. Any piping attached to isolated equipment, which includes not only pumps but cooling towers, compressors, boilers, refrigeration equipment, and fan coil units, must itself be isolated with an isolator having the same deflection as the isolated equipment for a distance of 50 feet or 50 pipe diameters, whichever is greater. At the first point of support an isolator having twice the pump deflection can be used, since when the pipe is drained it weighs considerably less than when it is full. The pump isolators are installed when the pipe is empty, and when it is filled the pump and pipe assembly drops down under the increased load. This motion may crack the pipe unless it is given the freedom to move. All piping must be resiliently supported either from the pump’s inertial base or with separate vibration isolators. In addition to isolating the pipe, flexible couplings can be installed near the pump. These serve to compensate for minor pipe misalignments and provide some vibrational decoupling for impulses transmitted along the pipe.

Fluid Pulsations

Occasionally the pulsations induced by a pump impeller will travel from the pump along the pipe and into a structure, through mechanical coupling between the pipe and a wall or floor. In existing buildings some reduction can be obtained by inserting a flexible coupling in the pipe between the pump and the receiver.

In high-pressure lines the impeller impulses may also be transmitted within the fluid so that a pulse dampener is recommended on the supply side of the pump after the flexible coupling. Pulse dampeners work in much the same way as a water hammer arrestor with an encapsulated gas-filled bladder. The pressure surge is allowed to expand into the bladder, which removes it from the liquid in the pipe. These devices are commercially available and are quite effective for attenuating vibrations in high-pressure lines including hydraulic lines.

15.5 MECHANICAL EQUIPMENT

Split Systems

Mechanical systems in residential structures provide heating, ventilating, and air conditioning (HVAC) services to the building. The thermodynamic principles were discussed in Chapt. 13. A typical system consists of an external air-cooled condenser, which gives up heat to the outdoors in the process of compressing a circulating refrigerant. The refrigerant is pumped through copper pipes to a fan coil unit where it is forced through an expansion valve and a coil, where it changes state from a liquid to a gas and absorbs heat from its surroundings. Air is blown over the cooling coil through which the refrigerant passes and heat is transferred to the coils and then to the refrigerant. Heat can be generated by an electric coil or separate gas-fired boiler.

Roof-mounted compressors, unless properly configured, can be a source of annoying vibration. Units should be installed as in Fig. 15.21. In wood buildings compressors are set on small platforms built of 3” (75 mm) lightweight concrete pads extending at least 12” (150 mm) beyond the outside of the unit. The unit itself is supported on 1” (25 mm) deflection spring isolators. Any electrical connections to the compressor are made using a minimum of 3’ (1 m) flexible wiring, which allows the unit to move freely back and forth and up and

FIGURE 15.21 Rooftop Condenser Installation

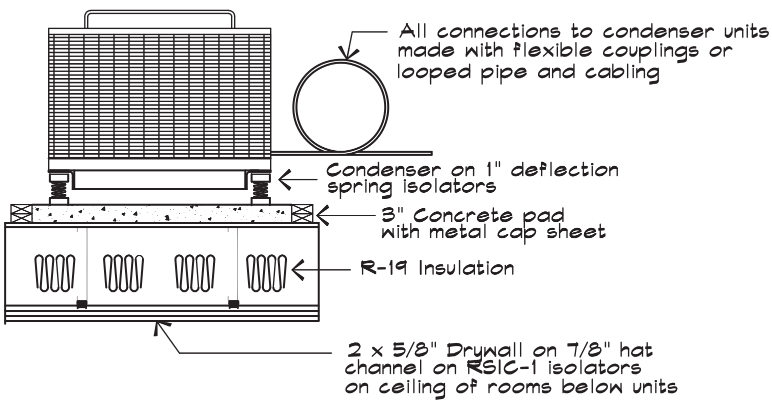
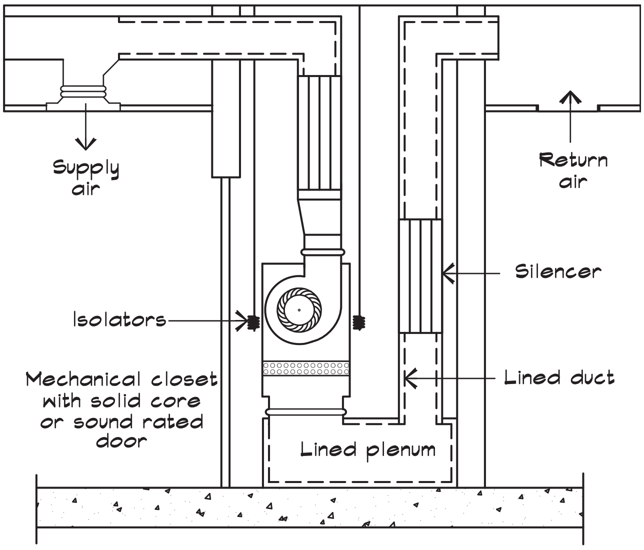


FIGURE 15.22 Vertical Fan Coil Unit



down on its isolators. Since the refrigerant lines are connected rigidly to the compressor it is good practice to wrap them one full turn around the unit before they penetrate the roof. This reduces the transmitted vibration that travels along the tubing. Refrigerant lines can create noise in the 35 to 40 dBA range if improperly isolated. They should be wrapped with foam insulation and be routed through a chase or within stacked fan coil closets. Where refrigerant lines are located in walls adjacent to critical areas such as bedrooms they should be wrapped with foam lead sheets. In any case they must not make direct contact with the structure or drywall.

Fan coil units are also a source of noise in residential buildings. They can be located in an attic in single-family residences or in a closet in multifamily dwellings and usually require a 3' (1 m) medium pressure drop silencer or equivalent loss in lined duct and elbows on the supply and return ducts to control duct borne noise. One effective mounting method is to arrange the fan coil vertically in a closet with a ducted supply and return as in Fig. 15.22.

Where the air is returned to the closet through a louvered panel located under the fan coil, noise levels are generally unacceptable, ranging from 45 to 55 dBA in the room containing the intake. Lining the area beneath the fan coil is of marginal value. Generally this space is too small to act as a plenum and at best becomes a lined elbow, which provides only a few dB of loss. Figure 15.23 shows a way of installing a fan coil or heat pump without a ducted return so that the return-air noise transmission path is attenuated by using a transfer-duct silencer. A heavy solid-core or sound-rated door with air-tight weather stripping, along with 2" (50 mm) fiberglass duct-liner board and 0.4" (10 mm) deflection neoprene isolators are necessary to properly isolate a vertical fan coil unit. Detailed calculations based on the casing radiated sound power levels of the unit can clarify the level of isolation required.

Packaged Units

Small packaged air handling units can be rooftop-mounted and contain a compressor, fan coil, and cooling fan in a single unit. These units are available in a side-discharge or

FIGURE 15.23 Fan Coil Unit with a Transfer Duct

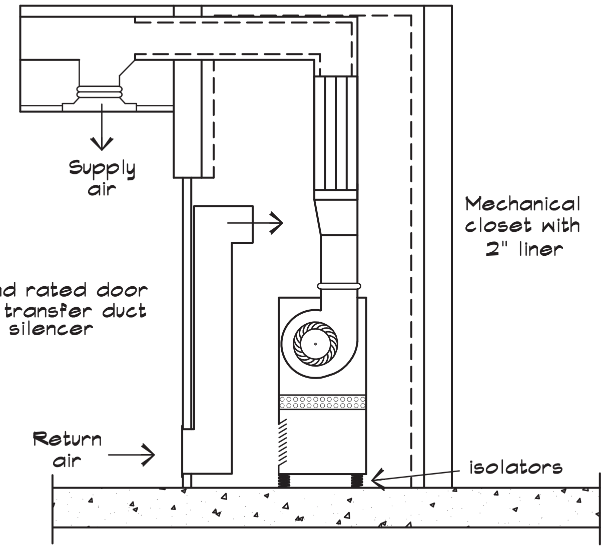
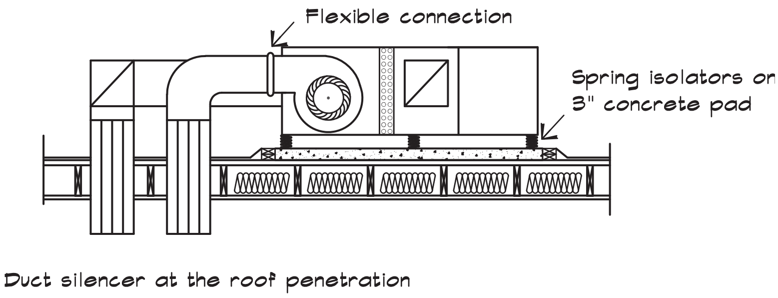


FIGURE 15.24 Roof-Mounted Packaged Air Handlers



down-discharge configuration. For purposes of noise control, the side-discharge units are much preferred since this allows space for the installation of silencers in a horizontal run of duct. In down-blast units, the air and noise issue straight down out of the unit, allowing very little room for a silencer or other attenuating mechanism. Figure 15.24 shows the preferred configuration for side-discharge units with silencers installed in the vertical drop. This location is optimal for the attenuation of both duct borne noise and exterior noise breaking into the duct.

Sound power levels associated with small packaged units vary according to the fan scaling laws discussed in Chapt. 13. They usually require some lined duct and either a 3’ (1 m) or a 5’ (1.5 m) medium pressure drop silencer to reduce levels to below an NC 30. An analysis along the lines of the calculation set forth in Chapt. 14 can yield the required attenuation.

Vibration isolation for these packaged units is similar to that for compressors. Rooftop units should be set on 3” (150 mm) lightweight concrete housekeeping pads and supported on 1” (25 mm) deflection spring isolators. In areas requiring seismic restraint separate limit stops are installed. Electrical connections are by means of 3' (1 m) long flexible cables. A flexible connection is used to couple the duct to the package unit. When they are located above critical areas, roof-mounted ductwork should be supported on neoprene isolators having a 0.25" (6 mm) deflection. Any condensate lines should be supported from the isolated equipment and not from the roof deck.

Roof-mounted boilers and associated piping must also be vibration isolated. Boilers with integral pumps need 1" (25 mm) deflection isolators and those with separate pumps should have 0.25" (6 mm) deflection neoprene mounts. Gas lines, which cannot include flexible connections, attached to isolated equipment should have four or more 90° bends separated by 3' (1 m) of straight pipe and be supported on 0.25" (6 mm) deflection neoprene isolators.

15.6 APPLIANCES AND OTHER SOURCES OF NOISE

Stairways

Footfall impacts on stairways can be conducted structurally through the studs, which support the stair risers. This, in turn, is radiated by the panels attached to the wall studs. In townhouse (two-story) condominiums and apartments it is good practice to locate the stairways on the interior of the unit away from the party walls. When this is not possible the stairways should be supported separately and the risers must not be physically attached to the wall framing or drywall. The party wall surface must be continuous behind the stairs and the treads, and risers and framing must not touch the drywall. Separate pipe columns may be used to support the stair landing and the diagonal supports should be attached only at the landing and the floor.

Appliances

In critical residential structures such as condominium units, free-standing appliances such as washers, dryers, and dishwashers should be isolated from the floor by using neoprene mounts. When this arrangement affects the lateral stability of the unit such as during a spin cycle in a washing machine, a lateral stabilizer may be necessary. This, too, should be in the form of a neoprene isolator having the same stiffness as the vertical one. The lateral stabilizer can be bolted to a crosspiece of plywood, which in turn is bolted to the washer. Quick acting valves in washing machines can cause water hammer in certain cases. Generally the hoses used to connect to the supply pipes have sufficient flexibility to dissipate the pressure pulse. Where this is not the case a water hammer arrestor located near the valve on the supply pipe will solve the problem and extend the life of the hose.

Garbage disposals present a unique set of problems for vibration isolation. Internally isolated units have become available, which have a shell within a shell construction and internal neoprene mounts. These are much preferred over the standard models, but they must be installed with a piece of flexible hose approximately 18" (450 mm) long to decouple the waste pipe from the disposal.

Jacuzzis

Jacuzzi tubs have an aerator, which mixes air with the tub water, and a circulation pump forces the mixture back into the tub in a closed-loop cycle. The combination can produce relatively high noise levels in multifamily dwellings both directly under the tub as well as in rooms adjacent to the epicenter. Noise levels as high as 50 to 60 dBA have been measured directly beneath a Jacuzzi tub in wood structures with lightweight concrete floors, and in the 40 to 50 dBA range in nearby rooms one floor below. Resiliently mounting the motor and pump provide some relief, on the order of 5 dB, but not enough to meet the levels set forth in Table 15.8.

In concrete structures Jacuzzi tubs have been installed on 4” (100 mm) concrete floating floors with 1” (25 mm) deflection spring isolators on a 6” (150 mm) slab. This approach addresses the sound and vibration problem but introduces a significant floor height change up to the base of the tub. The variation in floor height with the addition of water and bathers must also be accommodated. In general Jacuzzi tubs should not be installed in multifamily dwellings above the first floor.

Trash Chutes

Trash chutes are constructed of sheet metal tubes mounted in shafts, which carry trash from upper floors to a receptacle in the basement. They are best located in a masonry shaft, which is not on a wall of a dwelling unit. Shafts can be constructed of grouted concrete block units. Where they are located on common walls an additional batted stud wall with two layers of drywall, which does not make physical contact with the shaft wall, should be used to reduce their impact. Some authors (Harris, 1994) recommend that the steel trash chutes themselves be isolated and that the trash receptacles be covered with damping material.

Elevator Shafts and Equipment Rooms

Elevator shafts in multifamily dwellings and in office complexes are best located in a separate utility core, which is not contiguous to occupied spaces. Even if an elevator equipment room is remotely located, the elevator passage itself can cause noise levels in the 50 dBA range due to the vibration transmitted through the vertical guide rails. Where elevator shafts are located adjacent to occupied spaces a double stud double drywall wall has been used. Even in these cases vibration may still be transmitted into the adjacent space via the direct coupling of the rails to the slab or floor system.

Elevator equipment is either hydraulic or electric. Hydraulic equipment is located near the bottom of the shaft and consists of a pump, associated piping, and a thrust cylinder. The pump and piping is of greatest concern whereas the cylinder is rarely a factor. When the pump is located on a structural slab on grade below occupied areas it rarely presents a problem. Hydraulic pumps above grade should be vibration isolated using neoprene mounts. Code requirements prohibit flexible hose from being used as hydraulic lines so solid piping should be separated from the structure using isolators.

Electric winches control the elevator height by a cable wound on a drum located at the top of the shaft. In critical applications the drum and winch can be isolated by mounting the entire assembly on a concrete slab, which is set on isolators. Due to safety considerations, the mechanism must be designed so as to tolerate a failure or bottoming out of the isolation system.

Garage Doors

Where parking is provided below a multifamily dwelling or office building steel gates sometimes are installed for security. In an overhead installation the gate is supported at the sides on two vertical pipe columns attached top and bottom to the slabs. An electric motor hung from the slab above drives a chain or gear mechanism, which raises and lowers the gate.

When these gates are attached in this manner the vibration from the opening and closing of the gate can produce considerable annoyance to occupants of the floor above.

A preferable alternative to the overhead attachment is a side-opening gate, which is supported from below. Here the gate rides on a V rail and rolls to the side, driven by a chain drive motor bolted to the floor. In these installations a simple neoprene isolator supporting the track attached to the upper slab is usually sufficient to control the transmitted vibration. The important feature is that the upper rail system must not be directly coupled to the slab above. Where there is insufficient space for a side-opening gate an overhead gate can be supported using an independent structure on steel columns that do not make contact with the floor above.